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COMPLETE SPECIFICATION

Improvements in and relating to Electromagnetic Apparatus

We, THE BRITISH THOMSON-HOUSTON COMPANY, LIMITED, a British company having its registered office at Crown House, Aldwych, London, W.C.2, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

Our invention relates to electromagnetic apparatus, and more particularly to high speed operating apparatus having electromagnetic means for effecting an energy storing operation in combination with a magnetic release.

In a conventional form of operating mechanism for reciprocally operable apparatus such as a circuit breaker, for example, a spring is arranged to be stressed by a cam or the like for storing energy for a working stroke. The energy is released by suitable latching and tripping mechanism that is responsive in turn to an electromagnetic tripping impulse. Accordingly, it will be apparent that this type of mechanism is not only complicated but also involves a certain time lag due to inertia and lost motion after initiation of the tripping impulse.

A principal object of the present invention is the provision of an improved high speed operating mechanism of the electromagnetic type that is simple and compact in construction and capable of releasing without delay a large operating force. In accordance with the invention, an electromagnetic operating mechanism comprises a magnetic structure including a relatively movable armature arranged to form a magnetic circuit with a permanent magnet, the armature being reciprocally movable and comprising cylindrical portions of different diameters adapted to form with the magnetic structure separate holding surfaces normal to the direction of motion of the armature, a spring structure for biasing the armature toward an open magnetic circuit position for effecting a working stroke, an energising coil also related to the magnetic circuit for attracting the armature to the closed magnetic circuit position against the bias of the spring structure, the permanent magnet being effective solely to hold the armature at the holding surfaces in the closed magnetic circuit position against the bias upon de-energisation of the coil, and electromagnetic means (e.g. a separate coil) for establishing and concentrating an opposing flux at one of the holding surfaces for releasing the armature whereby the spring structure is effective to move the armature at high speeds to the open magnetic circuit position.

For a clearer understanding of the invention attention is directed to the accompanying drawings in which Fig. 1 is a sectional view in elevation of an electromagnetic device embodying the invention as applied to an electric circuit breaker; Fig. 1*a* is a partial view of the apparatus shown by Fig. 1 in the closed magnetic circuit position prior to tripping; Fig. 2 is a similar view illustrating a modified form of the magnetic structure shown in Fig. 1; Fig. 3 is a sectional view in elevation of another form of our invention also applied to a circuit breaker of the reclosing type; Fig. 4 is a graphical illustration of the reclosing characteristics of the apparatus shown by Fig. 3; Fig. 5 is a sectional view of another form of our invention that is capable of trip-free operation; Figs. 5*a*, 5*b* and 5*c* illustrate diagrammatically the various operating positions of the apparatus shown by Fig. 5. Fig. 6 is a sectional view in elevation of another form of trip-free apparatus as applied to a circuit breaker of the fluid blast type; Fig. 6*a* is a graphical illustration of forces involved in Fig. 6; Fig. 7 is a sectional view of a modified form of the magnet holding surfaces for increasing the effectiveness of the holding flux; and Fig. 8 is a perspective view illustrating a modification of the magnetic circuit arrangement shown by Fig. 7 for obtaining calibration of the holding force.

The electromagnetic device illustrated by Fig. 1 comprises a solenoid arrangement including an energising coil 1 and magnetic structure for completing a magnetic circuit for the coil flux including a pair of disc-like pole pieces 2 and 3. The pole piece 3, which comprises a disc composed of magnetic material, such as iron

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or steel, is provided with a central hub portion 3^1 extending part way within the coil 1 for co-acting with a movable armature 4 that is reciprocally guided within the opposite pole piece 2. The armature 4 is provided with a flange 4^1 arranged to engage the pole piece 2 co-incident with engagement of the lower end of armature 4 and pole piece 3^1. The armature 4 is also provided with an insulating or non-magnetic rod 5 for co-acting with a spring 6 so that the armature is biased toward the open magnetic circuit position shown. The spring 6 is seated between a fixed tubular extension 7 secured to the lower pole piece 3 and a flange 8 secured to the insulating rod. Accordingly, when the armature 4 is drawn within the solenoid in response to energisation thereof, the spring 6 is stressed and an energy storing operation is thereby performed.

For the purpose of holding the spring 6 under tension when the solenoid 1 is de-energised, there is provided a permanent magnet M comprising in the present instance a cylindrical member 9 composed of a precipitation-hardened permanent magnet alloy of the character described in our British Patent Nos. 423,897 and 424,746. This permanent magnet material has a very large magnetomotive force, the closed circuit flux output being of the order of 25 kilolines per square inch. This magnetomotive force is sufficient, even in the case of a small cylinder a few inches in diameter to maintain charged a comparatively powerful spring after the armature holding surfaces 2—4^1, and 3^1—4 have been brought into engagement. The above arrangement can be suitably assembled by mounting the coil 1 within the cylinder 9 and clamping the cylinder between the pole plates 2 and 3 by through bolts 10 or the like. With this arrangement the energising coil and permanent magnet use the same magnetic circuit.

It will be noted that the movable armature provides two separate holding surfaces, viz:—that at the lower side of the flange 4^1 and at the lower end of the plunger 4. These surfaces are normal to the direction of motion of the plunger, thereby insuring double use of the entire permanent magnet holding flux, and also a corresponding increase in the holding power.

Another expedient for increasing the holding power of the permanent magnet lies in designing the aforesaid holding surfaces for optimum area, that is, relating the holding area to the total holding flux so that a maximum holding power results. Also the two air gaps at the aforesaid holding surfaces and pole pieces respectively are related so that as the gaps are closed simultaneously the armature 4 is seated with considerable impact. In other words, the movable armature delivers a hammer blow simultaneously to each pole piece 2 and 3^1 so that the impact is transmitted to the permanent magnet M. This hammer blow has the effect of increasing the magnetomotive force of the permanent magnet in the presence of the magnetising flux of the main solenoid 1.

Assuming now that the armature 4 is in closed magnetic circuit position and is being held solely against the bias of spring 6 by the permanent magnet, the armature can be released by suitable electromagnetic means arranged to establish a flux opposing that of the holding magnet at one of both of the holding surfaces. Although this can be accomplished by momentary energisation of the coil 1 at reverse polarity, improved high speed operation results, if a small tripping coil 11 is disposed closely adjacent to one of the holding surfaces so as to build up a releasing flux at very high speed. Such a coil would be specially designed for high speed release and would preferably be of the character disclosed in our British Patent No. 500,472. In the above system the number of coil turns is an optimum for the rate of increase of the tripping flux.

The tripping coil 11 can be compactly mounted within an insulated annular pocket in the coil 1 as illustrated or can be suitably interleaved with the turns of the coil 1 at that location. In any event, the arrangement is preferably such that the tripping flux path through armature plunger 4 and the holding surfaces at 2 and 4^1 is of minimum length, in order to insure a maximum tripping speed. It will be noted that in the present instance the tripping flux threads both holding surfaces to oppose the magnet holding flux although the main releasing flux acts at 4^1. In view of the fact that the holding power varies as the square of the flux density, the effective holding flux need be reduced only about 10 or 12 per cent. in order to release the comparatively large spring force.

In order further to insure maximum speed of release of the spring energy, it is essential that the permanent magnet holding force decrease at a very rapid rate at the instant of separation of the holding surfaces. This is accomplished in the present instance by shunting most of the holding flux at the instant of separation so that it has minimum holding force. It is well known that it is less difficult to slide the keeper of a magnet across the holding surface by a shearing motion than it is to

pull the keeper directly away from the holding surface. In the present construction this characteristic is utilized by providing a thin insulating spacer, such as a fibre cylinder 12, 1/8" in thickness, for example, between the pole piece 2 and the plunger portion of the armature 4. Accordingly, when the holding surfaces at 2 and 4^1 start to separate the holding flux is progressively shunted directly across the insulating gap defined by the fibre spacer 12. This flux, however, is in a direction normal to the direction of motion of the plunger and therefore has minimum holding effect. The spring 6 therefore is effective to accelerate the movable armature very rapidly after this initial separation of the holding surfaces.

In the arrangement above described a fibre spacer 1/8" in thickness permits the reluctance of the path from the upper pole piece 2 to the plunger 4 through the insulating gap at the fibre spacer to equal the reluctance across the upper holding surfaces between 2 and 4^1 when the plunger is less than 1/16" away from its holding surfaces. Hence, as the plunger moves from direct contact to 1/16" stroke, the holding flux shifts from a direction parallel to the plunger motion where it has a maximum restraining force to a direction which is normal to the line of motion and hence has no force component restraining the plunger against the bias of spring 6.

The relation of the tripping flux to the holding flux is diagrammatically illustrated by Fig. 1*a* which illustrates the armature 4 in the closed magnetic circuit position where it is held solely by the permanent magnet flux indicated by the solid line arrows at H. As previously pointed out the main charging coil or solenoid 1 is de-energised at the completion of the charging stroke. When the high speed working stroke under influence of the spring 6 is to be performed, the tripping coil 11 is energised so as to establish an opposing or tripping flux indicated by the chain arrows at T for decreasing the effectiveness of the holding flux H. As illustrated, the flux H normally takes a path through the holding surfaces at 2—4^1 and 4—3^1 normal to the direction of motion of the plunger, returning by way of the source of magnetomotive force, i.e., the permanent magnet M. The tripping flux T tends to shunt the holding flux H around the tripping coil as indicated by the dotted line path, and to this end the coil 11 is comparatively short and compactly arranged adjacent to the holding surfaces at 2—4^1, so that the reluctance of the aforesaid shunt path for the flux H need not be greater than necessary.

This compact arrangement of the trip coil 11 with respect to a holding surface of the magnetic circuit results in high tripping speed by reason of the short iron path for the tripping flux and the short shunt path for the deflected holding flux.

The modification illustrated by Fig. 2 is designed further to increase the tripping speed. In this case the tripping coil 11 is provided with a cup-like magnetic shell 11^1 suitably secured to the fixed pole piece extension 3^1 for decreasing the reluctance of the path for the tripping flux. In the closed position of the armature 4 the magnetic circuit for the tripping flux is complete, except for the essential gap at the point 13. It will also be noted that the magnetic shell or cup 11^1 within which the tripping coil is mounted also serves to decrease the reluctance of the shunt path for the flux H during the tripping operation as illustrated in Fig. 1*a*. The cross-section of the core 11^1 is small so as to saturate quickly in the presence of the closing ampere turns. By energizing the trip coil reversed in parallel with coil 1, both can aid in closing the device.

The tripping flux path is further shortened at the upper holding surfaces by countersinking the flange 4^1 of the plunger armature with respect to the pole piece 2. That is, the length of the flux path from the pole piece 2 to the plunger 4 is now decreased substantially by the thickness of the pole piece 2. A further advantage of this arrangement is that the stroke of the plunger can be decreased and thereby the size and weight thereof decreased accordingly, so that the inertia of the moving element is reduced. This inertia is even further reduced in the present arrangement by arranging the charging spring 6 above the solenoid so that a short connecting rod 14, as compared with the rod 5 of Fig. 1 which extends through the lower pole piece 3, can be used. The spring 6, as in the previous instance, normally biases the plunger 4 toward open magnetic circuit position and is seated between a fixed bracket support 15 mounted on the pole piece 2 and a disc 16 secured to the rod 14. The means to be actuated is suitably related to the member 16.

As previously stated the present invention is applicable to reciprocally operated apparatus such as circuit breakers, but it should be understood that the invention is not limited thereto and may, for example, have general application as a thrust-transmitting mechanism.

Referring again to Fig. 1, the device is illustrated as applied to a specific form of oil circuit breaker of the fluid blast type. The circuit breaker obviously may be of

any suitable type and, in the present instance comprises a cylindrical casing 17 depending from the lower pole piece 3 and partly filled with oil to a level indicated. The circuit breaker structure comprises a pair of relatively movable contacts, such as a fixed contact 18 suitably mounted in the bottom of the casing and connected to a circuit terminal 19, and a movable contact 20 connected to the lower end of the plunger rod 5 and also suitably connected through conductors 21 and 22 to the other circuit terminal 23. The movable contact rod is also provided with a piston 24 operable within an insulating cylinder 25 having an opening at 26 for the movable contact. The cylinder 25 is also provided with a port 27 communicating with the main oil body. A one-way valve 28 is likewise mounted in the cylinder 25 for preventing retardation of the piston during the opening stroke.

When the device is tripped to open the breaker contacts 18 and 20, the spring 6 drives the piston 24 upward co-incident with opening movement of the contact 20 so as to force oil as indicated from the port 27 across the arc path at the lower part of the casing to exhaust at 29 through an upper partition 30. Accordingly, the working stroke of the spring 6 can be utilized to accomplish not only a circuit-opening operation, but also an effective arc-extinguishing blast of a suitable medium. The breaker is closed by energisation of the solenoid 1 which also recharges the spring 6, resets the device with respect to the permanent magnet holding flux, and recharges the permanent magnet.

Under certain operating conditions it is highly desirable that a circuit breaker be adapted to reclose within a very short time after interrupting a fault current. The reclosing speed should not appreciably exceed the time required for interrupting the fault current and therefore must be of the order of a few cycles of commercial frequency. An important characteristic of the electromagnetic device above described resides in high speed reclosing ability.

In the arrangements shown by Figs. 1 and 2 the trip coil 11 is not necessarily used for the reclosing cycle. The charging coil 1 can be simply energised at reverse polarity as indicated at S (Fig. 1) to trip the breaker and to effect the high speed reclosing operation as graphically illustrated by Fig. 4. As the coil current starts to build up at reverse polarity, the device trips as in the previous instance by the flux-shifting or flux-opposing principle, since the holding flux H is now directly opposed by the flux of the charging coil. Accordingly, the spring 6 functions to open the mechanism even before the coil current has increased to its normal value. However, as the coil current continues to build up, the permanent magnet is charged with reverse polarity, and the movable plunger 4 is immediately retracted again to close the magnetic circuit and also the circuit breaker. The charging coil circuit is then interrupted and the permanent magnet functions as before to maintain the spring charged until another tripping operation is performed.

The operation can be clearly understood by reference to the graphs of Fig. 4. In the closed position, the permanent magnet has, for example, a holding force of approximately 1500 pounds. Assuming that the opposing spring force is 1200 lbs., a tripping flux equivalent to but 300 lbs., is necessary. This flux is indicated as corresponding approximately to 10 amps. in the solenoid circuit, at which point tripping occurs as shown at t by the Travel graph. As the solenoid current continues to increase the polarity of the holding magnet is reversed and the holding force is reduced to zero. Further increase in the solenoid current causes the reclosing force to build up as clearly shown by the Force graph. When the reclosing force reaches a predetermined amount, the inertia of the moving structure is overcome and reversal or reclosing thereof is initiated at r as shown by the Travel graph. After reclosure the solenoid current is interrupted and simultaneously the solenoid force is replaced by the holding force of the permanent magnet. The apparatus is then in condition for another reclosing cycle that is started by energising the solenoid with reversed polarity.

A subsequent reclosing operation is performed by simply again reversing the polarity of the charging coil and the above cycle is repeated. It will be apparent, of course, that where the tripping coil 11 is also used in this arrangement for normal tripping the polarity of the tripping coil would automatically be reversed in accordance with reversal of the polarity of the coil 1, in order to maintain a proper tripping relation of the interacting fluxes.

By way of example, we have found that a device which has a $2^1/_2''$ stroke and a maximum charge spring pressure of 1500 pounds can be reclosed by the above method in 0.25 seconds. This is considered to be excellent reclosing time since an increase in the speed might in certain cases be undesirable due to possible incomplete clearance of the fault and the presence of ionized gas.

It will also be apparent that reclosing can be accomplished simply by energising

the tripping coil 11 and thereupon immediately energising the coil 1 at normal polarity. This method is also comparatively fast, the reclosing time for a specific device being but one cycle slower than by the reverse polarity method above described.

The main charging coil 1 is, in the present instance, composed of a single coil energised from a direct current source. However, where a direct current source is not available, the solenoid can comprise two separate coils interleaved and operated from a source of alternating current through a full wave rectifier. Where two coils are used, a series connection is employed for 250 volt operation and a parallel connection for 125 volt operation. In case of parallel operation the two coils must have the same characteristics, and to this end the coils are interleaved so as to have the closest possible coupling. If not, and the two windings have different resistances, it is possible by parallel connection to make the device close and remain closed only as long as current passes through the two windings in parallel. When the total current is interrupted the device will no longer remain closed, but will trip open because a complete circuit still remains in the parallel connection whereby the difference in the two coil currents is a reverse component in one coil producing an unwanted tripping action. However, when the two coil currents are interrupted separately, the device remains closed under influence of the permanent magnet flux until a tripping flux is established in the manner above described.

The present invention is not primarily concerned with the remote control system for energising the charging and tripping coils, and it will be apparent that the energising circuits can be controlled by simple manual switching means, or by the usual relay system for automatic operation. Also, both methods of control may be combined in a well known manner as in the case of automatic circuit breakers.

Fig. 3 illustrates a modified form of the invention wherein the permanent magnet M comprises a disc 31 secured as at 32 between the upper pole piece 2 and a steel disc 33. The magnetic circuit is completed by a magnetic cylinder 34 and the lower pole piece 3 through which the movable plunger armature 4 operates. As in the previous instance, the armature 4 is designed to make simultaneous butt contact at the pole piece 3 and disc 33. A fibre spacer 35 serves to maintain the proper flux insulating gap between the plunger and the pole piece 3, along the side parallel to the direction of motion.

For the purpose of facilitating the tripping operation, two separate tripping coils 36 and 37 are compactly arranged adjacent to the two holding surfaces at 3 and 33. Accordingly, when the device is to be tripped the coils 36 and 37 can be energized either separately or simultaneously, to establish an opposing flux at the holding surfaces for permitting immediate opening of the armature under the influence of spring 6.

The present arrangement shown as applied to a simple form of circuit breaker comprises a pair of fixed contacts 38 and 39 and a co-acting bridging contact 40. The insulating operating rod 41 of the circuit breaker is in effect a continuation of the plunger rod 5 and has affixed thereon a piston 42 operable within a fixed cylinder 43 depending from the lower pole piece 3. The spring 6 is seated between a fixed shoulder 44 in the cylinder 43 and the movable piston 42 so as to bias the plunger 4 and the bridging contact 40 toward the open position. The piston 42 in opening the breaker functions also as a blast producing device, the conduits indicated at 45 at the lower end of the cylinder being utilized in any suitable manner for directing an arc-extinguishing fluid into the arcs. Although the action of the piston 42 on the fluid at the lower part of the cylinder 43 serves to cushion the latter part of the opening stroke, a rubber buffer 46 seated on the shoulder 44 can also be provided for this purpose.

As in the case of the cylindrical form of permanent magnet, the disc form of magnet in Fig. 3 is fully recharged on each energisation of the solenoid 1, and this charging action is intensified by the closing impact due to the plunger 4. By way of example, we have found that a device constructed according to Fig. 3 and provided with a disc magnet 5″ in diameter and 1″ thick of precipitation-hardened permanent magnet alloy has a holding force of approximately 1500 pounds that is effective to control 1200 pounds of stored spring energy. It will therefore be apparent that such a device is capable of initiating within a small fraction of a second a powerful high speed working stroke notwithstanding the small simple compact structure involved.

It will be apparent that the device above described is also capable of operating through a high speed reclosing cycle, the reverse polarity method previously described being preferred. Fig. 4 also illustrates graphically the reclosing performance of this device.

In Fig. 5 there is illustrated a modification of our invention particularly applicable to circuit breakers where the

so-called trip-free action is desired. That is, when the circuit breaker is closed on a fault the breaker is immediately tripped open notwithstanding continued energisation of the closing mechanism. Referring more particularly to Fig. 5, the permanent magnet M in the form of a cylinder 9 is provided as in the case of Fig. 1 with upper and lower pole pieces 2 and 3 and a main spring-charging coil 1. In the present case, however, the magnet is provided with two separate armatures 48 and 49 arranged to co-act with the pole pieces 2 and 3 respectively. A stationary iron core 50 is mounted centrally of the coil 1 for completing the magnetic circuit. The armatures 48 and 49 are normally biased in opposite directions by a spring 51, and to this end the armature 48 is provided with an operating rod 52 terminating in a piston member 53 which serves as a seat for the upper end of the spring 51, and the armature 49 is provided with a suitable extension 54 serving as a seat for the lower end of the spring. It will therefore be noted that when the spring is compressed the armatures are biased in opposite directions.

In the position illustrated the device is in the open position, the upper or anchor armature 48 being seated on the pole piece 2, so that when the coil is energized the energizing flux serves, together with magnet M, to hold the anchor armature in such position. As the lower armature 49 is drawn into the solenoid toward the fixed armature 50, the spring 51 is compressed against the fixed piston 53 of the anchor armature. Accordingly, when the armature 49 makes contact at 3 and 50, the magnetic circuit is completed so that the coil 1 can be de-energised and the two armatures held against the respective pole pieces against the bias of spring 51 by the permanent magnet flux.

Assuming now that the device is in closed position and is to be tripped in the normal manner, a trip coil 55 disposed adjacent the holding surfaces at the pole piece 3 and armature 49 is energised to establish a flux opposing the holding flux. The spring 51 is thereupon effective to return the apparatus to the position shown. If now trip-free operation is desired, a second tripping coil 56 disposed adjacent the holding surfaces of the pole piece 2 and anchor armature 48 is energised during the normal closing stroke above described so as to release the anchor armature. When this takes place the upper end of the spring at 53 is no longer restrained with the result that the spring cannot be recharged even though the armature 49 is moved by the closing coil to its fully closed position. Where the operating force of the coil 1 is comparatively large it may be desirable to energise both trip coils 55 and 56 for the trip-free operation above described.

For the purpose of diagrammatically illustrating the application of the above device to a circuit breaker, reference is had to Figs. 5*a*, 5*b* and 5*c* which illustrate the open, closed and trip-free positions respectively of the device. The circuit-controlling contacts are indicated at 57 and 58 and are connected to the anchor armature 48 and the lower or charging armature 49 respectively. Fig. 5*a* illustrates the circuit breaker in open position with the anchor armature in the holding position. In Fig. 5*b* the charging coil has raised the armature 49 so as to close the contacts. Normal tripping is accomplished simply by releasing the armature 49 so that the contact 58 again drops to the position shown in Fig. 5*a*. In Fig. 5*c*, however, the anchor armature is released for trip-free operation during closing with the result that this time contact 57 moves upward to break the circuit. Resetting of the device to the position shown in Fig. 5*a* takes place under the influence of gravity when charging coil is de-energised so that the two armatures are released.

In case of normal tripping by one coil, it may be advantageous to provide a positive flux in the other coil so as to assist in maintaining in position the armature which is functioning as the anchor.

The device shown by Fig. 6 is similar in principle to that disclosed by Fig. 5 and provides for normal closing, high speed tripping, trip-free operation during any part of the closing stroke and high speed reclosing. The device is shown as applied to a circuit breaker of the fluid blast type; and as in the previous instance comprises a main spring-charging coil 1, and anchor armature 48 and spring-charging armature 49. The permanent magnet structure, however, in the present instance is of the disc type and comprises two separate magnet discs M_1 and M_2 suitably assembled with respect to a steel spacing plate 60 and fixed steel pieces 61 and 62. The upper and lower pole pieces 2 and 3 are spaced as in the case of Fig. 3 by a steel cylinder 63 for completing the magnetic circuit.

Accordingly, when the anchor armature 48 is locked in position by the holding flux of magnet M_1, energising of the charging coil 1 is effective to raise the armature 49 and compress the spring 6 in the manner described in Fig. 5. As in the previous instance the anchor armature 48 is provided with an operating rod 64 slidably

guided in the permanent magnet structure and armature 49. Secured to the rod 64 is a piston 65 comprising a seat for the upper end of the spring 6. The lower end of the spring seats at 66 in a cylinder 67 carried by the armature 49.

The circuit breaker structure operatively connected to the armatures 48 and 49 respectively comprises a pair of relatively movable contacts 68 and 69 arranged for circuit-controlling movement in the manner diagrammatically illustrated in Figs. 5*a*, 5*b* and 5*c*. In the present instance, the anchor armature rod 64 is secured to a tubular member 70. The tubular member 70 is provided with a port 70^1 located above the piston 65 so that upward movement of the piston is effective to drive fluid from the cylinder 67 downward through the tubular member 70 and the tubular contact 68 that forms therewith a continuous fluid passage. The contact 68 can be suitably insulated from the magnet structure by means of an insulating coupling 71. The co-acting contact 69 is suitably carried by the armature 49 by means of insulating supports 72 constituting in effect a frame depending from the cylinder 67. The contacts can be connected to the external circuit at the terminal 68^1 and 69^1 respectively.

It is believed that the circuit-controlling operation is apparent from the previous description. In the open-circuit position shown, the anchor armature 48 is held fast by the flux of the permanent magnet M_1 and the apparatus is in readiness for the closing operation which is effected by the charging coil 1. During the charging operation the piston 65 remains fixed and the armature 49 is raised to compress the spring 6. If the breaker is being closed on a fault, the trip coil 36 immediately establishes a releasing flux at the anchor armature 48. The spring 6 is now effective to drive the piston 65 upward as the anchor armature is released with the result that a high velocity blast of fluid is directed through the tubular contact 68 and into the arc path between the separating contacts 68 and 69. This action can be concurrent with continued upward movement of the armature plunger 49 to closed position. It will be noted that the above-described blast action takes place, either in case of trip-free operation, or during normal high speed tripping, since in both cases there is relative movement between the piston 65 and cylinder 67 tending to drive fluid through the contact 68. As in the case of Fig. 5 the tripping coil 37, located adjacent to the holding surface of armature 49, is also provided for tripping the aforesaid armature for normal opening. It will be apparent, of course, that normal tripping can be accomplished by releasing either armature 48 or 49 by suitable energisation of the trip coil 36 or 37 respectively.

In order that the charging flux of the coil 1 shall be more effective to assist the magnet M_1 in holding fast the anchor armature 48, the steel spacer 60 can be notched at 60^1, as illustrated to provide a more saturable path, so that the charging flux will not be mainly shunted through that part of the magnetic circuit. During the aforesaid charging operation the magnet M_2 being in series with the main charging flux is charged for the subsequently holding duty. In order to insure proper charging of the magnet M_1 a separate coil 73 can be provided for this purpose.

Fig. 6*a* illustrates diagrammatically the force-travel relation between the spring 6 and the permanent magnet and charging coil for the above type of operating mechanism.

Referring to Fig. 7 there is shown a modified form of armature wherein the pole pieces 2 and 3^1 and the co-acting armature 74 are provided with a plurality of concentrically arranged holding surfaces thereby increasing by several times the total holding force of the permanent magnet flux as compared with a device in its most simple form. That is, the total holding flux is gainfully used a plurality of times. In this arrangement the armature 74 is provided with two concentrically arranged ringlike members 75 and 76 of magnetic material spaced at 77 to form an annular insulating gap. The members 75 and 76 are assembled with respect to the armature operating rod 79 by means of an insulating plate 78. The pole piece 2 is likewise provided with an annular insulating gap 80 arranged staggered with respect to the gap 77 of armature 74, so that the flux from the permanent magnet M threads the armature and pole pieces as illustrated at four separate holding surfaces. The area of these holding surfaces is of course designed so that it is an optimum with respect to the holding flux produced by the magnet M. The above arrangement, although increasing somewhat the reluctance of the magnetic circuit, increases by several times the total holding force produced by the magnet flux. The tripping flux of the coil 11 is effective to cause release of the armature in the manner above described by reducing the holding force at the adjacent holding surfaces below the opposing force of the spring. That is, the loss of holding power at the innermost holding surfaces adjacent to the tripping coil is sufficient

to cause tripping, since as previously pointed out tripping can be accomplished by a reduction of but approximately 10% of the holding flux.

For the purpose of calibration where a comparatively sensitive device is required, the armature 74 and co-acting pole piece can be designed so that simply by rotating the armature 74 the holding force can be varied between wide limits. To this end the ring 76 of the armature, instead of being a continuous steel member, is formed as alternate sections of non-magnetic material or insulation 81, and steel 82 as illustrated by Fig. 8. For co-acting with the armature 74 the inner part of the pole piece at 83 is similarly constituted of alternating insulating and steel sections 84 and 85 respectively.

It will therefore be apparent, referring again to Fig. 7, that the path for the total holding flux can include in series either a high reluctance or a low reluctance section simply by rotating the armature 74 with respect to the fixed pole piece 2 so that the insulating and magnetic sections are either in alinement or staggered to the degree desired.

It should be understood that our invention is not limited to specific details of construction and arrangement thereof herein illustrated, and that changes and modifications may occur to one skilled in the art without departing from the spirit of our invention.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. Electromagnetic operating mechanism comprising a magnetic structure including a relatively movable armature arranged to form a magnetic circuit with a permanent magnet, the armature being reciprocally movable and comprising cylindrical portions of different diameters adapted to form with the magnetic structure separate holding surfaces normal to the direction of motion of the armature, a spring structure for biasing the armature toward an open magnetic circuit position for effecting a working stroke, an energising coil also related to the magnetic circuit for attracting the armature to the closed magnetic circuit position against the bias of the spring structure, the permanent magnet being effective solely to hold the armature at the holding surfaces in the closed magnetic circuit position against the bias upon de-energisation of the coil, and electromagnetic means (e.g. a separate coil) for establishing and concentrating an opposing flux at one of the holding surfaces for releasing the armature whereby the spring structure is effective to move the armature at high speed to the open magnetic circuit position.

2. Electromagnetic operating mechanism as claimed in Claim 1 in which the armature is a movable plunger reciprocally guided for simultaneous butt contact at a plurality of holding surfaces with the magnetic structure.

3. Electromagnetic operating mechanism as claimed in Claim 1 or 2 in which the magnetic structure includes means for establishing a minimum flux path length for the opposing flux at the holding surface.

4. Electromagnetic operating mechanism as claimed in Claim 3 in which the magnetic structure adjacent said normal holding surface is spaced by an insulating gap of the order of one-sixteenth of an inch from a surface of the plunger that is parallel to the direction of motion thereof whereby slight initial movement of the plunger under influence of the spring bias effects shifting of the holding flux from the normal surface to the parallel surface for insuring high acceleration of the working stroke.

5. Electromagnetic operating mechanism as claimed in Claim 3 or 4 in which the plunger has an annular flange arranged to seat in a corresponding recess in the magnetic structure so as to form holding surfaces both normal and parallel to the direction of motion of the plunger.

6. Electromagnetic operating mechanism as claimed in any preceding claim provided with means arranged to reverse the polarity at the energising coil of the magnet for establishing a flux opposing the holding flux thereby causing a working movement under the bias of the spring means, the energising current in the coil at the reverse polarity subsequently causing immediate reclosure of the armature.

7. Electromagnetic operating mechanism as claimed in any preceding claim of the trip-free type, comprising a movable armature coacting with a solenoid, a permanent magnet and an anchor armature coacting therewith, a spring operatively interconnecting the armatures and arranged to be stressed when the anchor armature is held closed by the permanent magnet coincident with actuation of the first-named armature by the solenoid, and electromagnetic means for establishing an opposing flux at the anchor armature for releasing the same irrespective of energisation of the solenoid.

8. Electromagnetic operating mechanism of the trip-free type as claimed in Claim 7 comprising a pair of movable armatures coacting with pole pieces fixed to a permanent magnet structure, circuit

controlling contacts connected to both the armatures respectively, a spring interconnecting the armatures so as to bias the contacts toward open circuit position, the flux of the permanent magnet structure being effective to hold one of the armatures against the spring bias, an energising coil for attracting the other armature so as to compress the spring against the permanent magnet holding force, and a tripping coil for establishing a flux opposing the holding flux for permitting tripfree operation of the contacts during the closing stroke.

9. Electromagnetic operating mechanism as claimed in Claim 8 in which the premanent magnet structure comprises a pair of magnets each coacting with an armature and having a tripping coil for establishing a flux opposing the holding flux of the magnet.

10. Electromagnetic mechanism as claimed in any preceding claim comprising an armature having a plurality of coacting holding surfaces spaced by insulating gaps so that the holding flux established by the magnetomotive force threads the armature and magnetic structure at a plurality of different points for increasing the armature holding force, said coacting holding surfaces each having non-magnetic sections alternating with magnetic sections whereby the holding force can be calibrated by relative movement of the armature in a plane parallel to the holding surfaces.

11. Electromagnetic operating mechanism constructed and arranged for operation substantially as described with reference to the accompanying drawings.

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